

8<sup>th</sup> International Conference on Traffic and Transportation Studies  
Changsha, China, August 1–3, 2012

## Optimizing the Usage of Walking Facilities between Platform and Concourse Layer in L-Shaped Interchange Metro Station

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### Abstract

This paper has focused on the analysis of pedestrian flow characteristics for 3 different groups of walking facilities including two-way escalator, ascending escalator combined with descending stairway, and descending escalator combined with ascending stairway between platform and concourse layer in an L-shaped interchange metro station. Data were collected by field observations to develop flow-density-speed relationship for each group of walking facility and analysis has been done to compare pedestrian flow characteristics and walking behavior on various groups of facilities. It has shown that walking facilities in the station discussed are not properly used for the pedestrian flow in rush hours and not safe, and an optimized usage of those facilities has been proposed according to the station structure and the analysis above. The data collected and the analysis done in this paper can be used as a basis for changing the usage of existing facilities, and will become an important reference for future pedestrian flow theory research in the same kind of metro stations.

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*Keywords:* walking facility; pedestrian flow; interchange metro station; travel behavior; flow characteristics

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### 1. Introduction

With the development of those giant Chinese cities like Shanghai, their urban metro networks are also

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experiencing expanding processes. Interchanges metro stations especially the ones located in the downtown area of those cities are now suffering more flow pressure from the passengers if compared with past years. For the sake of complicated building structure of the densely located mansions beside, the design of interchange stations and their walking facilities should be suit the circumstances. Therefore, specific structure such as an L-shaped interchange station would certainly have conflict zones of bidirectional pedestrian flow in the corner part of the shape “L”. However, even if the structure of the station cannot be changed, the pedestrian flow can be effectively guided to form a newly self-organized behaviour which is safer if the walking facilities between the concourse and platform layer have been properly used to make their best according to the pedestrian flow characteristics of such station. Moreover, the research above can help to reduce the potential security hazard in interchange stations caused by improper usage of walking facilities, which is of huge significance for the whole city metro system.

Researchers in Europe had the earliest start of the pedestrian flow study on certain walking facilities in certain places. Oeding, D. (1963) gave the basic concept that different walking facilities had different pedestrian flow characteristics and different models should be built according to each one; Fruin, J. J. (1971) pointed out that walking facilities should be designed according to different pedestrian flow characteristics in different places so as to improve the quality of service; Older, S. J. (1968), Navin, F. D., et al. (1969) and Seneviratne, P. N., et al. (1990) had analyzed the pedestrian flow characteristics of several different walking facilities in shopping streets and CBDs. Researchers in Asian countries started their related research in this area in late 1980s, but several research results with high reference value based on the behavior of pedestrian on walking facilities with the background of the different culture in Asia had been published ever since. Tanaboriboon, Y., et al. (1986,1991) had done research on the pedestrian flow characteristics of different walking facilities in Singapore and Bangkok, and had pointed out that the design standard of walking facilities should be set according to the specific situation of each city; Koushki, P. A. (1988) and Lam, W. H. K., et al. (1995) studied the flow-speed relationship of walking facilities in downtown area of Riyadh and Hong Kong separately, and pointed out that those facilities had higher maximum capacity than the same kind of facilities in Europe cities by comparison; as it came to the walking facilities in metro stations, Gerilla, G. P. (1995) and Cheung Chung-yu (1998) made their discussion on the capacity of stairways and horizontal walking channels in Philippine and in Hong Kong separately, while Chen Xiaohong et al. (2007) had studied the pedestrian flow characteristics of interchange walking channels and had pointed out several problems on the existing standards related.

It can be seen that related research on certain walking facilities in certain places had been started for almost 50 years, even if those research had clarified that the pedestrian flow would be varied if place changed, and many suggestions had been made to help set the design standard of walking facilities, there are still some problems: first, research on capacity of walking facilities in interchange metro station with large passenger flow is rare; then, even if Helbing, D., et al. (1997) and Muramatsu, M. (1999) had discussed the self-organization of bidirectional pedestrian flow in crowded situation, but it is hard to find certain research getting those theory above and pedestrian flow characteristics of walking facilities combined to discuss the impact on bidirectional self-organization behaviour by walking facilities in interchange metro station; last but not the least, there are hardly any research on the usage of different walking facilities in interchange stations such as whether to let a certain escalator running upward or not. Consider that it has great importance to reasonably use the walking facilities in those interchange metro stations in downtown area, in this paper, Caoyang Road Station, a station with 3 metro lines interchanging in it has been set as the place of doing case study, by studying the capacity and pedestrian flow characteristics of 3 groups of walking facilities including two-way escalator, ascending escalator combined with descending stairway, and descending escalator combined with ascending stairway between the concourse and platform layer of the overground part of this station, the drawbacks in current usage of

walking facilities have been pointed out and the optimization scheme without reconstructing the existed walking facilities has been proposed according to the distribution of the pedestrian flow.

## 2. The objects of study and related data acquisition

### 2.1. The objects of study

Caoyang Road Station is placed in northwest of the downtown area in Shanghai, it is a station with 3 metro lines (line 3, 4 and 11) interchanging in it. As it is an L-shaped interchange station, both the overground part and the underground part are the arms of “L”, and the passenger flow for interchange are both coming from the corner side of “L”, the situation is almost the same. So, in this paper, only the walking facilities in the overground part of the station are discussed. The overground part is for line 3 which connects Baoshan in the north and Xuhui in the southwest part of Shanghai and line 4 which is almost parallel with inner ring road of Shanghai, besides, as the underground part is for line 11 which connects the west suburban District Jiading and the city center, the pressure of passenger exchanging is extremely large. At present, the overground part for line 3 and 4 has a passenger flow of 100'000 in each day, and 15'000 person/h in the rush hours.

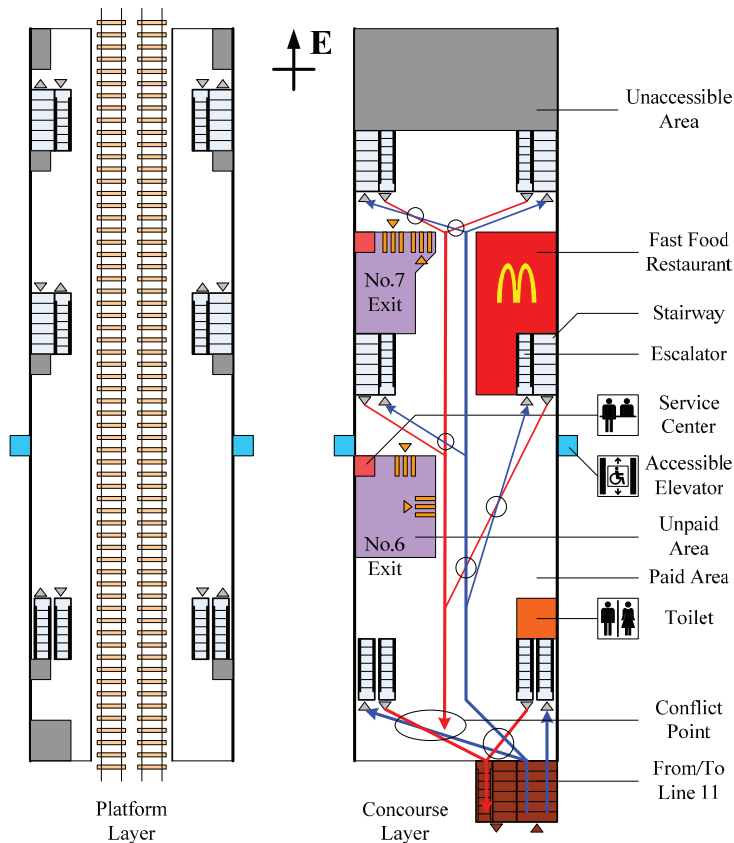


Fig. 1. Schematic plan of the overground part of Caoyang Road Station

The schematic plan of the overground part for line 3 and 4 is shown in Fig. 1. There are 6 groups of walking facilities in it, which are all the objects of study in this paper. As the distances between each group of walking facilities and the interchange channel are different from each other, each one has its own pedestrian flow, density and speed characteristics at the same time. Basically, the 2 groups of two-way escalator located in the west part of station have the most passenger flow for the closeness to the interchange channel. On the other side, statistics made by operation company shows that the passenger flow from, or to the downlink and uplink platform are almost the same, and consider that the parameters such as effective width, step width and step height of all the escalators in those 6 groups are the same, so are all the stairways, in order to simplify the discussion, the pedestrian flow characteristics and capacity in rush hours of only the 3 groups of walking facilities in the north and their proper usage are studied in this paper. The physical parameters of those 3 groups of walking facilities are shown in Table 1.

Table 1. Physical parameters of the 3 groups of walking facilities studied

Walking Facility	Parameters
Two-way escalator	Effective width: 1.05m, step width: 0.38m, step height: 0.24m, speed: 1.6 steps per second for each escalator.
Ascending escalator combined with descending stairway	Effective width: 1.05m, step width: 0.38m, step height: 0.24m, speed: 1.6 steps per second for escalator; Effective width: 1.68m, step width: 0.3m, step height: 0.15m for stairway.
Descending escalator combined with ascending stairway	Effective width: 1.05m, step width: 0.38m, step height: 0.24m, speed: 1.6 steps per second for escalator; Effective width: 1.68m, step width: 0.3m, step height: 0.15m for stairway.

## 2.2. Data acquisition

In the study discussed, the data acquisition method given by Teknomo, K., et al. (2001) employing video recording, dynamic passenger recognition and automatic data counting is used. Data of pedestrian flow of those 3 groups of walking facilities in rush hours are collected. All the video records are cut into with the time length at 20s samples to study the flow, density and speed parameters. 20s is chosen as the sample time length because long time samples would cause the statistics of the parameters to become average for the periodicity of the passenger flow digested by the facilities. In other words, long time samples would help nothing in observing the maximum capacity of each walking facility.

$$density = \left[ \sum_{i=1}^M \left( \frac{\text{number of passengers on } n \text{ steps}}{\text{effective width} \times \text{step width} \times n} \right)_{\text{sample } i} \right] / M \quad (1)$$

$$speed \text{ in stairway} = \left[ \sum_{i=1}^M \left( \frac{\text{step width} \times n}{\text{time used for } n \text{ steps}} \right)_{\text{sample } i} \right] / M \quad (2)$$

$$speed \text{ in escalator} = \left[ \sum_{i=1}^M \left( \text{escalator speed} + \frac{\text{step width} \times n \text{ if moved}}{\text{time of observation}} \right)_{\text{sample } i} \right] / M \quad (3)$$

In the parameters studied, the unit of flow is 1/(min·m), it means the number of passengers observed in each video sample passing certain cross-section divided by the product of observing time (20s) and effective width of certain walking facility; the unit of density is 1/m<sup>2</sup>, it means the average number of passengers per unit area, it can be get from equation (1) after counting the number of passengers on n steps in M instant samples from the 20s video, however, in the analysis of pedestrian flow characteristics

“space” is more often used with the unit , it is the inverse of density which means the average area each passenger took; the unit of speed is m/min, the pedestrian speed on stairway and escalator can be get from Eqs. (2) and (3) after getting the related information of M passengers in 20s video.

### 3. Data analysis

According to the observation and data acquisition method, by video recording in the morning and evening rush hours and then cutting into 20s samples at first, and by intelligent passenger recognizing as well as manual data sorting at last, the flow-space and the speed-space statistical distribution graphs of the 3 groups of walking facilities can be get for further analysis.

#### 3.1. Group 1: two-way escalator

220 video samples were gotten from each escalator of the walking facilities in group 1, and the flow-space and the speed-space statistical distribution graphs are shown in Fig. 2. and Fig. 3. From speed-space graphs it can be seen that no matter how the density changes, the speed of pedestrian flow is above a certain value (see the horizontal lines), and this certain value can be get as 36.48m/min from the product of escalator convey speed (1.6 steps per second) and step width 0.38m. Just because the escalator have an inherent speed, if passengers stay still on it, the pedestrian flow can also be changed as several certain values along with the changing of average density of the passengers on the escalator, as the curves in flow-space graph show.

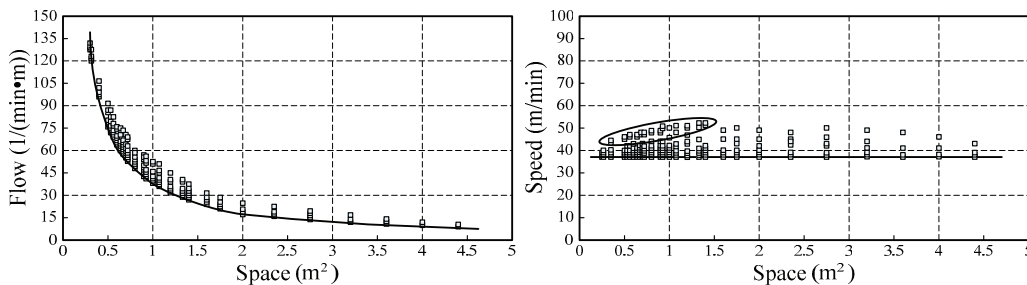


Fig. 2. Flow-space and speed-space statistic diagram for ascending escalator in Group 1

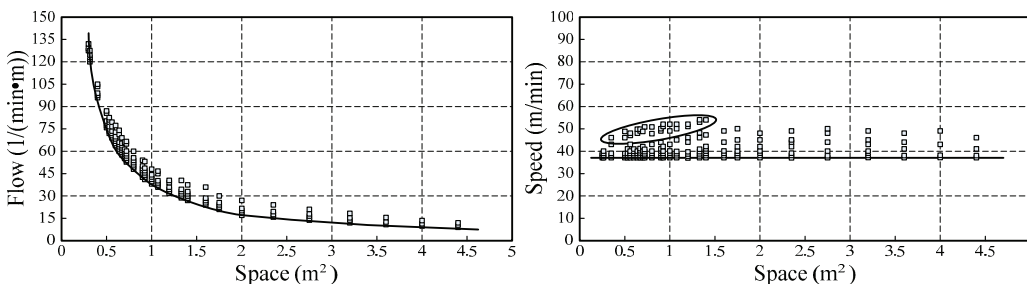


Fig. 3. Flow-space and speed-space statistic diagram for descending escalator in Group 1

From the statistic results in Fig. 2. and Fig. 3., it can be easily seen that the speed of pedestrian flow on the escalator is not kept at the inherent speed but always a little bit faster, also, the pedestrian flow is a little bit higher than the curve depicts, these statistic results reflect that there are also some kind of

behavior like takeover happened on the escalators. The results above has shown the facts that unlike Chen Xiaohong et al. (2007) had discussed, there are also flow behavior on the escalators just as there are on the staircases.

It should be pointed out that in the samples with higher pedestrian density, some have the same speed-space statistical feature and different from most of the other samples as shown in the oval-shaped circle. By analysis in detail, these samples are all gotten from the morning rush hours in which office workers take up a large part of the pedestrian flow, and the “left right rule” for escalator can be executed better, so at that time the escalator can realize a speed much higher than the inherent value even if the density of pedestrian flow is high.

### 3.2. Group 2: ascending escalator combined with descending stairway

150 and 240 video samples were gotten from the ascending escalator and descending stairway of the walking facilities in group 2 separately, and the flow-space and the speed-space statistical distribution graphs are shown in Fig. 4. and Fig. 5. The maximum density observed for the ascending escalator in this group is lower than the one in group 1 for it is father from the corner of shape “L”, namely, the interchange channel. Apart from this, there are no obvious differences in flow-space and speed-space statistical distribution feature because the physical parameters are the same between the 2 ascending escalators in different groups.

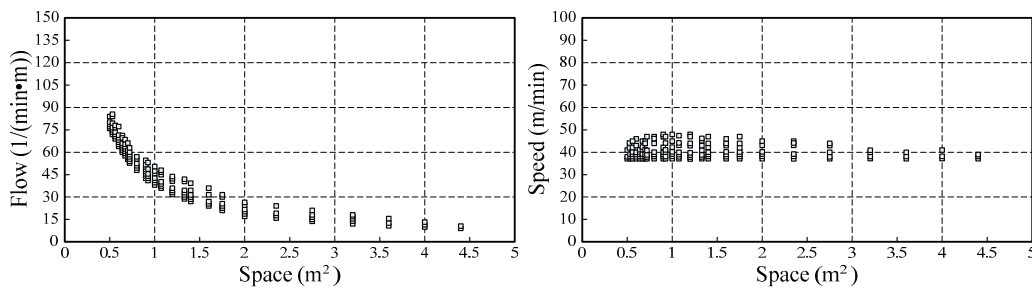


Fig. 4. Flow-space and speed-space statistic diagram for ascending escalator in Group 2

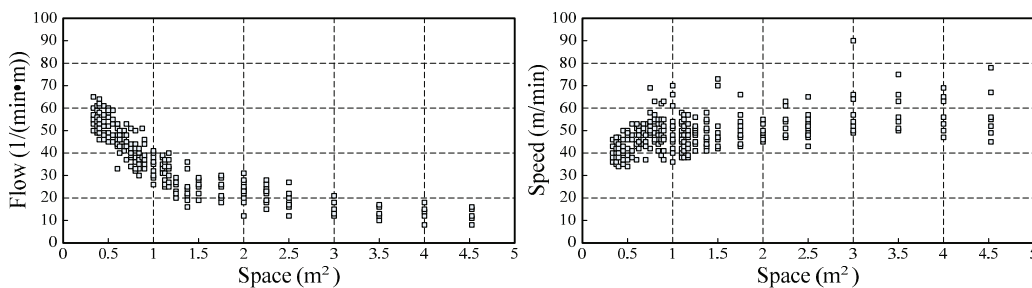


Fig. 5. Flow-space and speed-space statistic diagram for descending stairway

From the statistical distribution shown in Fig. 5. it can be seen that walking on the stairway can be more casual without the affect from the inherent speed of walking facility. Moreover, all the individuals are different from each other. When the density is lower, the casualty and the individuality is obvious to be observed, behavior like jumping steps, takeover, move round etc. happen all the time; while when the

density is relatively higher, the occurrence of those behavior above are almost 0 and all the passengers tend to have the consistent behavior with the space constraint, the whole pedestrian flow realize its self-organization and acts as a parade to go ahead.

### 3.3. Group 3: descending escalator combined with ascending stairway

Another 150 and 240 video samples were gotten from the descending escalator and ascending stairway of the walking facilities in group 3 separately, and the flow-space and the speed-space statistical distribution graphs are shown in Fig. 6. and Fig. 7. The walking facilities in group 3 are located in the end part of the L-shaped station and they are the farthest ones from the interchange channel, so the density of the pedestrian flow on both the stairway and escalator are lower than the last group, but the flow-density-speed statistical distribution of these walking facilities still has the same pattern with the ones in group 2.

It should be noted that the walking facilities in group 2 and 3 are next to the exit of the station, but the pedestrian flow on them are still lower, that means the pedestrian flow for interchange is evidently greater than the flow for in and out in this station.

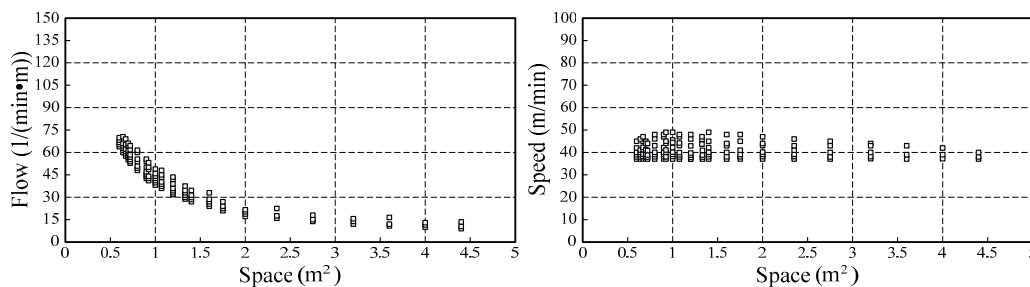


Fig. 6. Flow-space and speed-space statistic diagram for descending escalator in Group 3

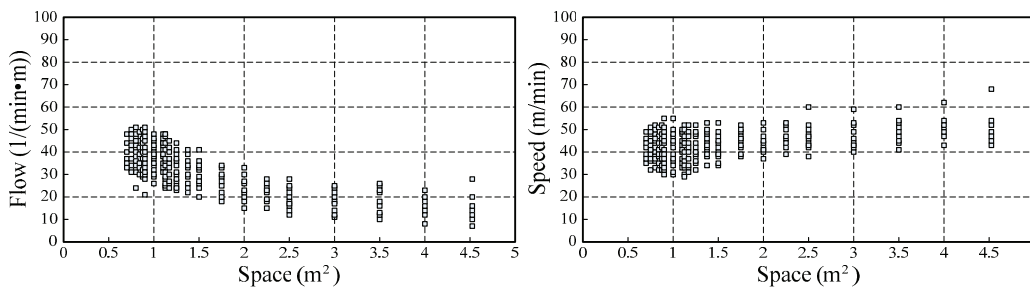


Fig. 7. Flow-space and speed-space statistic diagram for ascending stairway

## 4. Usage optimization

### 4.1. Present situation of walking facilities usage

In Fig. 1, the usage of all the walking facilities in the station discussed has been shown. In current usage scheme, by the analysis above based on the field observation, the pedestrian flow characteristics can be understand, as shown in Table 2. It can be seen that during rush hours, the density of the pedestrian flow on the walking facilities in group 1 is the highest, which has exceeded the 3 people/m<sup>2</sup> quota for severe overcrowding defined by Chen Yanyan, et al. (2011). Moreover, according to the “Code for



Design of Metro” set by Chinese State Ministry of Construction, et al. (2003), the capacity designed for escalator, ascending stairway and descending stairway in metro station should be 8100/(h•m), 3700/(h•m) and 4200/(h•m). That is to say, the two escalators in group 1 are running in maximum capacity in rush hours while the walking facilities in group 2 and 3 are not and can face larger pedestrian flow. As discussed above, the pedestrian flow for interchange is evidently greater than the flow for in and out, it is unsafe to let the facilities in group 1 shoulder the main pressure of the pedestrian flow from the interchange channel.

Table 2. Pedestrian flow characteristics of walking facilities observed

Group	Walking Facility	Maximum Capacity Observed (1/(min•m))	Maximum Density (1/m <sup>2</sup> )
1	Ascending escalator	135	>3
	Descending escalator	135	>3
2	Ascending escalator	85	2
	Descending escalator	64	3
3	Ascending escalator	72	1.67
	Descending escalator	51	1.5

In current usage scheme for the 3 groups of walking facilities, without considering passengers in and out from the exits, in the concourse layer, passengers from the platform layer and interchange channel can follow the guide of sign and their sights self organize their behavior to form pedestrian flow as Fig. 1. shows. From the figure it can be seen several conflict points is appeared in the concourse layer, and the most two serious ones are just near the interchange channel. The places that have pedestrian flow conflict points have large amount of passengers passing by, and the walking facilities nearby are running in maximum capacity, so, it is unreasonable to use the facilities to help guide passengers self-organized and form the pedestrian flow according to the current scheme and it has a higher security risk if any emergency happens.

#### 4.2. Usage optimization

According to the analysis above, in order to reduce the security risk, the usage of the 3 groups of walking facilities should be changed so as to help guide passengers to self-organize themselves better and form safer pedestrian flow, as shown in Fig. 8. Without considering passengers in and out from the exits, the newly self-organized pedestrian flow would bring evidently less conflict points in the concourse layer after changing the usage of the walking facilities. There would be only 1 conflict points near the interchange channel and other ones are moved far from the corner of shape “L”. The optimized usage of walking facilities has taken full account of the passenger flow in the interchange channel. The walking facilities in group 1 separates the pedestrian flow that coming from the north platform and going to the south platform according to the flow direction in interchange channel, and the left pedestrian flow that coming from the south platform and going to the north platform must use the facilities in group 2. Thus, the importance of the walking facilities in group 2 have been promoted, and at least 50% of the pedestrian flow for interchange should use the facilities in group 2 and 3, it is no doubt the pressure that the walking facilities in group 1 shoulder would be effectively reduced.



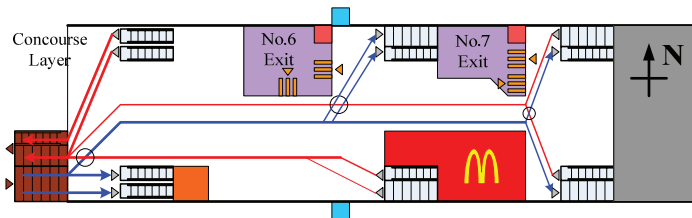


Fig. 8. Optimized usage schemes of walking facilities

## 5. Conclusions

In this paper, a typical L-shaped interchange metro station – Caoyang Road Station in Shanghai is set as an example to discuss the usage of walking facilities in certain metro stations with high passenger flow in it. Long time field video observing, computer data acquiring and manual data sorting have been done to get large amount of effective statistics data, by drawing the statistical distribution graphs which reflect the flow-density-speed characteristics of pedestrian flow on the 3 groups of facilities between the concourse and platform layer in the overground part of the station, the features have been found for all the walking facilities and the improperness of the current facility usage scheme has been pointed out according to the standards related. Moreover, an optimized usage scheme has been proposed based on the field situation and the feature of pedestrian flow distribution, the scheme can evidently reduce the conflict points of pedestrian flow in the concourse layer without reconstruct the existing walking facilities, and make the best of all their capacities. The collected data and the analysis done in this paper can be used as a basis for changing the usage of existing facilities and for future pedestrian flow theory research in the same kind of metro stations.

## Acknowledgements

This paper is partly supported by National Basic Research Program of China under Grant No. 2007AA11Z247, National Natural Science Foundation of China under Grant No. 61074139, Science and Technology Commission of Shanghai Foundation under Grant No. 10511500303, 10ZR1432200.

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